QUANTIFYING THE ROLE OF PHYSICAL PROCESSES IN THIN LAYER FORMATION AND MAINTENANCE[1]
LARGE SCALE PHYSICAL FORCING OF THIN LAYER DYNAMICS[2]

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LONG-TERM GOAL

Our long-term goal is to understand how physical mechanisms influence the formation, maintenance and dispersion of thin layers of phytoplankton and zooplankton. This understanding will help us to predict the frequency and occurrence of thin layers, and to identify other coastal regions that are favorable for thin layer development.

OBJECTIVES

Our first objective was to complete the analysis of data gathered during the 1998 'Circulation Study' in order to identify the physical processes that control circulation in East Sound. Our second objective was to complete and submit a manuscript detailing these processes and circulation patterns. Our third objective was to make significant strides in processing the physical data measured during the 1998 'Thin Layers Experiment'. Our fourth objective was to investigate the relationships between large scale physical forcing, water circulation in East Sound and the temporal and spatial patterns of thin layers.

APPROACH

We participated in a series of multidisciplinary cruises conducted in East Sound, WA (Figure 1) in 1996 and 1998. In 1996 cruises were conducted to test new instruments and deployment techniques utilized to quantify optical and acoustical thin layers. In 1998 a larger multidisciplinary experiment was undertaken to directly address the physical and biological mechanisms controlling thin layer

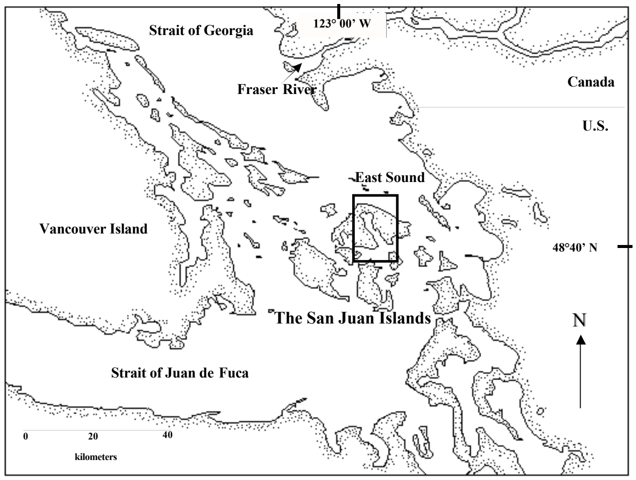

Figure 1. Location of study area

dynamics. This experiment included the 1998 'Circulation Study' (25 May to 1 June), the 1998 'Thin Layers Experiment' (10 June to 24 June) and a cruise in support of a Naval Research Laboratory hyper-spectral over-flight (27 July to 8 August).

First, we have completed our analysis of data from the 1996 experiment. The processed data sets have been incorporated into a master statistical database. Second, we have completed our analysis of data from the 1998 'Circulation Study'. Results from the 1998 'Circulation Study', which detail the circulation of East Sound, have been submitted as a manuscript to 'Estuarine Coastal and Shelf Science'. Finally, the analysis of the data from the 1998 'Thin Layers Experiment' is proceeding. A summary of fully processed data from the 1998 'Thin Layers Experiment' is listed below.

WORK COMPLETED

(1) We have completed the analysis of data from the 1998 'Circulation Study'. Results from this study have been submitted to 'Estuarine Coastal and Shelf Science'. Title of Manuscript: M.M. Dekshenieks, T.R. Osborn, P.L. Donaghay, J.M. Sullivan. submitted. Observations of General Circulation Patterns in East Sound, Washington. Estuarine Coastal Shelf Sci.
(2) We have processed a 2.5 month time series of data from 2 SeaBird Seagauge wave and tide gauges, measured during the 1998 'Thin Layers Experiment'. This data has been provided to principal investigators (PIs) in the 'Thin Layers Project'.
(3) We have processed 2.5 month time series of data from a wind station, measured during the 1998 'Thin Layers Experiment'. This data has been provided to PIs in the 'Thin Layers Project'.
(4) Along with Dr. P.L. Donaghay and Mr. J.M. Sullivan, we have processed a 12 day time series of CTD data from 2 autonomous underwater winches, measured during the 1998 'Thin Layers Experiment'. Preliminary contour plots have been distributed to PIs in the 'Thin Layers Project'. The title of this distribution is: Autonomous Underwater Winch Profiler Data Summary I: Preliminary contour plots of temporal changes in temperature, salinity and sigma theta structure in East Sound, WA between June 12 and June 25, 1998. P.L. Donaghay, J.M. Sullivan, M.M. Dekshenieks.
(5) We have completely reprocessed 1.5 week, and 2 month time series of data (two separate deployments) from 4 RD Instrument bottom-mounted 0300 kHz acoustic Doppler current profilers (ADCP) and 1 Sontek bottom-mounted 1500 kHz ADCP, measured during the 1998 'Circulation Study' and the 1998 'Thin Layers Experiment'. This processing is complete. The original and reprocessed data, from all bottom-mounted ADCPs for both deployments, as well as the complete

documentation are being written to CD-ROMs for distribution. This data will be distributed to all PIs in the 'Thin Layers Project' by 15 November 1999.
(6) We have collaborated with Dr. J. Yoder and successfully acquired SeaWifs Imagery data of the Strait of Juan de Fuca and Strait of Georgia region during the 1998 'Thin Layers Experiment'.
(7) We have presented our results in a series of invited talks and at the data workshop associated with the 'Thin Layers Project'.

- Invited speaker for a special session on thin layers. American Society of Limnology and Oceanography (ASLO), Santa Fe, NM, February 1999. Title of talk: Dekshenieks, M.M., P.L. Donaghay, T.R. Osborn, A.D. Weidemann, D.R. Johnson, Factors controlling the circulation in East Sound and the concomitant generation of thin layers.
- Invited lecturer for the Oceanography Department Seminar Series at the University of Washington. University of Washington, Seattle, WA, April 1999. Title of lecture: Dekshenieks, M.M., P.L. Donaghay, T.R. Osborn, Observations of general circulation patterns in East Sound, Washington.
- Participated and helped with organization of the 1999 Thin Layers Data Workshop. University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, May 1999.
- Invited lecturer for the Coastal and Estuarine Geophysical Fluid Dynamics Summer Class. Friday Harbor Laboratories, Friday Harbor, WA, July 1999. Title of lecture: Dekshenieks, M.M., P.L. Donaghay, T.R. Osborn, The circulation of East Sound and thin layer generation.

RESULTS

Results from the 1998 'Circulation Study' show that on a local scale, winds and tides are the primary processes driving water circulation in East Sound. We have identified four basic patterns for the currents associated with the possible combinations of flood or ebb tides, with winds up or down the Sound. Profiles of the currents show a layered flow with a vertical scale of 2 to 8 meters. Local wind and tides, however, are not the only forces generating the observed circulation patterns in East Sound. Freshwater input, the Coriolis force and bathymetry are secondary processes influencing water mass movement in East Sound.

We have also observed that in contrast to fjords with large river inflows at their upper end, the primary source of freshwater to East Sound is exterior to the Sound. As a result, the water mass 'type' in East Sound is highly dependent on regional-scale wind and tidal mixing occurring in the channels surrounding the San Juan Islands. Our observations agree with work done by Griffin and LeBlond (1990). Their results show that pulses of low salinity water from the Strait of Georgia are periodically advected into the Strait of Juan de Fuca during neap tide, when tidal mixing in the channels is at a minimum. In addition, when winds are northwesterly, the pulse of low salinity water being advected through the channels is significantly enhanced (Griffin and LeBlond 1990, Hickey et al. 1991).

From preliminary analysis of data from the 1998 'Thin Layers Experiment' we observe a pulse of low salinity water in both salinity data from the wave tide gauges (Figure 2a) and contours of hourly profiles of salinity from the autonomous underwater winch profiler (Figure 2c). This pulse of low salinity water arrives in East Sound during neap tide (a period of low tidal mixing) (Figure 2a), following three days of northwesterly winds (from June 10 through June 12). Measurements of currents show higher velocities in the transition stage before the full pulse of low salinity water arrives in the Sound (Figure 2d). Similar pulses of low salinity water have been recorded on at least three additional occasions during the 1998 'Thin Layers Experiment'.

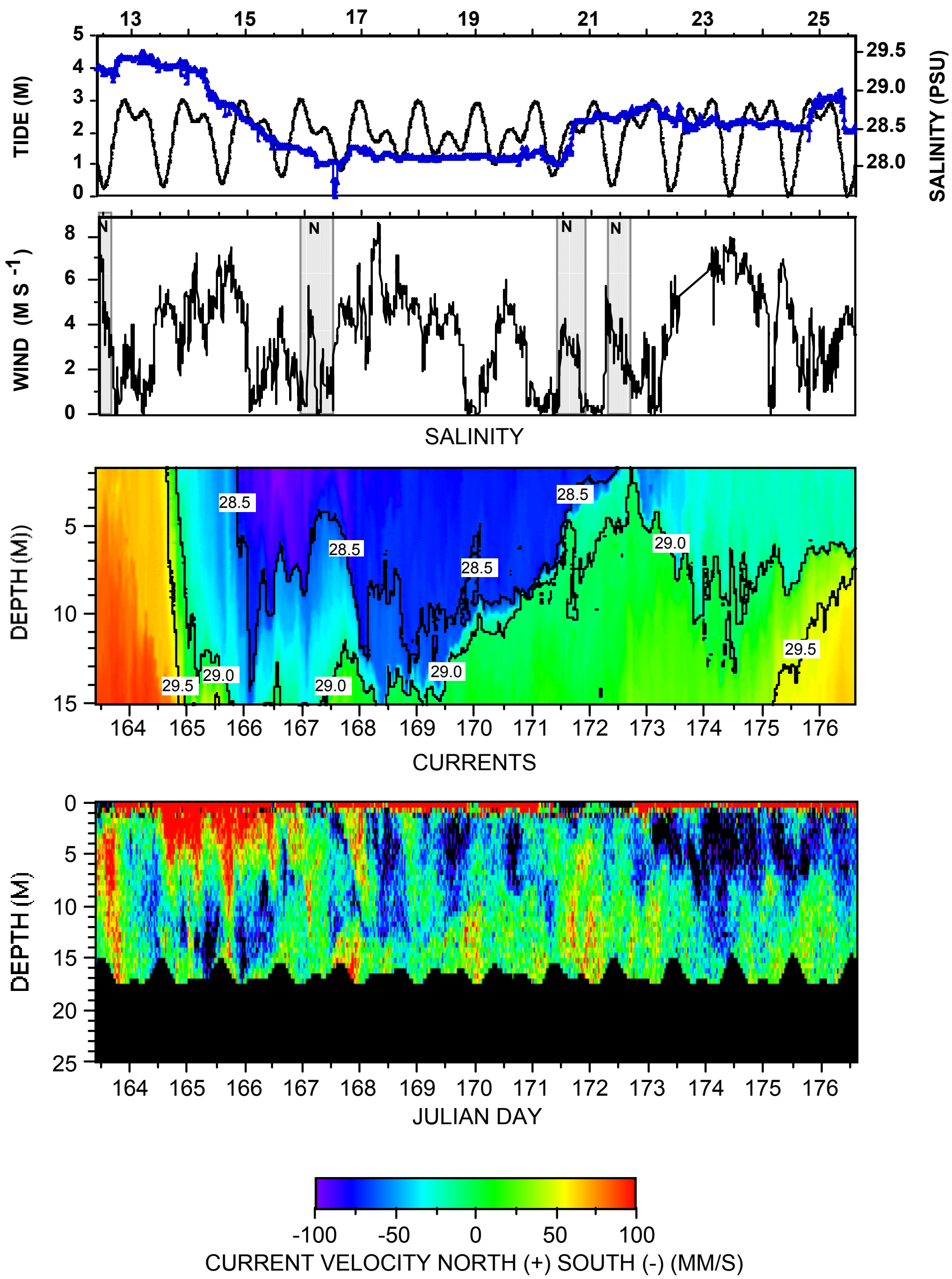

Figure 2. (A) Tidal height (m) (black), bottom salinity (psu) (blue) from a wave tide gauge. (B) Wind speed (m/s) (black), wind direction (N/S). (C) Salinity (psu) vs. depth (m) from an underwater winch. (D) North/south current velocity (mm/s) from a 300 kHz ADCP.

Preliminary analysis of simultaneously collected optical data from the 1998 'Thin Layers Experiment' illustrates that pulses of low salinity water from the Strait of Georgia substantially impact spatial patterns of thin layers in East Sound. We have made a critical connection between large scale physical forcing, pulses of low salinity water and thin layer dynamics. Each low salinity event provides a 'restart' to the system. This provides us a unique opportunity to study the time evolution of thin layers.

IMPACT/APPLICATIONS

Thin layers can have important impacts not only on the biological structure and dynamics of marine systems, but also on the optical and acoustic properties of those systems. As a result, it is critical that we develop techniques to detect such structures and to predict their dynamics and impacts. The strong statistical relationship between thin layers and physical structure as well as theoretical arguments (Donaghay and Osborn 1997, Osborn 1998) indicate that we cannot understand layer dynamics without understanding physical forcing and bio-physical interactions at both small and large scales.

TRANSITIONS

The software developed for this project is being transitioned for use in the Ocean Response Coastal Analysis System (ORCAS) autonomous underwater profilers. This project involves partners at the Naval Research Laboratory (Stennis Space Center), and the Naval Oceanographic and Meteorological Command. This project was funded under the National Ocean Partnership Program (NOPP).

RELATED PROJECTS

The purpose of this project is to provide PIs in the 'Thin Layers Project' with a larger context of physical circulation, within which the finescale and microscale biological and physical processes that control thin layer dynamics may be addressed. Clearly, in order to interpret small scale patterns in biological distribution, it is necessary to understand the larger scale circulation patterns.

(1) Alice Alldredge and Sally MacIntyre (UCSB) are investigating patterns of thin layers of marine snow, and how these patterns are related to turbulent microstructure in East Sound.
(2) Tim Cowles (OSU) is investigating how interactions between small-scale physical, optical and biological processes contributes to the formation of thin layers of phytoplankton in East Sound.
(3) Percy Donaghay (URI) is investigating how both biological and physical process contribute to the temporal and spatial patterns of thin layers of phytoplankton and zooplankton in East Sound.
(4) Dian Gifford (URI) is studying grazing processes and the structure and persistence of thin biological layers in East Sound.
(5) D.V. Holliday, Charles Greenlaw, Duncan McGehee (Marconi Aerospace Defense Systems) and Rick E. Pieper (USC) are using new acoustical technology for the study of thin layers of zooplankton.
(6) Mary Jane Perry (UMaine) is investigating the mechanisms responsible for the variability in phytoplankton biomass, primary production, and species composition in thin layers in East Sound.
(7) Jan Rines (URI) is studying the interactions of small-scale physical mixing processes with the structure, morphology and bloom dynamics of non-spheroid diatoms leading to thin layers.
(8) David Smith (URI) is investigating bacterial abundance, production and community composition in thin biological layers in East Sound.
(9) Ron Zaneveld and Scott Pegau (OSU) are investigating the physical and optical characteristics of thin layers in East Sound.

REFERENCES

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Hickey, B.M., Thomson, R.E., Yih, H. and LeBlond, P.H. 1991. Velocity and temperature fluctuations in a buoyancy-driven current off Vancouver Island. JGR. 96(C6): 10507-10538.

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PUBLICATIONS

Dekshenieks, M.M., Osborn, T.R., Donaghay, P.L. and Sullivan, J.M. submitted. Observations of general circulation patterns in East Sound, Washington. Estuarine Coastal Shelf Sci.